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Development of Long Range Radio Control System for an Unmanned Disaster Relief Helicopter

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Abstract: In this research work, Long Range (LR) radio control system has been developed for an unmanned disaster relief and survey helicopter. The proposed radio control system is developed to overcome the short communication range problems in unmanned helicopters in initial off-the-shelf configurations. System development approach has been used to identify the available radio components, to integrate the components to implement the system and to test the implemented system. Developed LR radio system has been successfully tested for its range and endurance. For range testing, change in servo motor angles with respect to distance has been measured and analysed. Maximum range of 48 km has been achieved, using the proposed system, and endurance of 2.5 hours has been predicted by measuring the drawn current by the proposed LR radio control system.

Key words: Radio control, Disaster relief and surveying, Unmanned aerial vehicle (UAV), System development.

INTRODUCTION

Climate changes and annual frequency of large-scale climate anomalies, such as, typhoons, cyclones, floods and droughts, have rapidly escalated globally during the past few decades (Keiler, 2013). Developing countries are particularly susceptible to the disastrous consequences of natural disaster and climatic anomalies, as in the past decade. In Pakistan alone, annual floods (Tariq and van de Giesen, 2012) and 2005 earthquake (Durrani *et al*., 2005) caused a loss of countless lives and unprecedented infrastructural damage (Memon, 2012; Dworkin, 1974). Furthermore, the lack of adequate rescue and surveillance facilities exacerbated the rate of preventable casualties and caused additional hurdles in the way of carrying out search-and-rescue operations in remote and desolate Northern areas of the country. The casualties would have been much reduced, had there been adequate and extensive facilities available to quickly scan the disaster struck areas and precisely guide rescue efforts (Ahmad, 2012). Usually, military helicopters are used for both survey and rescue, but such operations are very costly to manage and operate.

Although, many Government departments, United Nations (UN) and various Non-Governmental Organizations (NGOs) are involved in disaster management, but they lack adequate facilities and equipment to search and survey the affected areas and to provide rescue services in an effective and timely manner.

Unmanned Aerial Vehicles (UAVs) provide a relatively cheap solution for disaster surveillance, management and recovery operations, and to guide the rescue teams in right direction to save precious lives (DeBusk, 2010; Adams and Friedland, 2011). Use of UAVs has many advantages over full scale surveying. These include less deployment time required, inverted flight, easier maneuverability, agility and very low safety concerns (Larsen, 2010). However, there are also some disadvantages, such as limited payload capacity and limited flight range. For surveillance purposes, unmanned helicopters are considered as the most suitable choice due to their higher maneuverability, agility and less effect due to wind disturbances (Iqbal *et al*., 2015a).

There is very less literature available on the development of unmanned disaster relief helicopters because most of the rescue operations and the subsequent research is done by the defence organizations of the country and the work has not been published. As a result, there is a scarcity of fully equipped unmanned disaster surveying helicopters available to civil organizations.

The purpose of this research is to develop a fully functional surveillance and disaster recovery-based unmanned helicopter for civilian usage and academic research, while keeping within the confinements of

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local resource constraints and fulfilling the specific indigenous requirements. Once the helicopter is developed commercially, different government departments and NGOs can utilize them for commercial, academic and disaster recovery applications. This research involves some national security issues due to which the usage of the unmanned helicopter system will only be allowed to some authorized organizations to minimize the potential terrorism risks and damages.

This paper presents one part of the overall research project aimed to develop an unmanned helicopter indigenously from a medium-sized hobby helicopter for disaster surveying and relief operations. Overall project involves the development of LR vision system (Fazl-e-Umer *et al.*, 2014), development of LR radio control system, structural improvements (Iqbal *et al.*, 2016a), development of airdrop mechanism (Iqbal *et al.*, 2016b; Sadiq *et al.*, 2016) and a high performance efficient engine. While, this paper only focuses on the development, implementation and testing of the LR radio control system.

DeBusk (2010) and Elston and Frew (2010) reported that the practical implementation and working of UAV is severely lagging in civil sector rather than military, due to national security issues and constraints. In this article, a case study on implementation and application of UAV in disaster relief is carried out. Operational constraints, due to defense and military restrictions, have consistently limited the research in the field of UAV. The existing UAVs have been used for storms (Elston and Frew, 2010), tornados, wild fires (Merino *et al.*, 2005), floods (Hervouet *et al.*, 2011), earthquakes, civil disturbances, chemical spills and urban disasters (Spraying, 2002).

Sato (2003) developed an unmanned helicopter (developed by Yamaha) and employed it for the chemical spraying to ease farmers in Japan. The type of helicopters can also be used for relief purposes (after minor modifications) and as research platforms in educational institutions for UAV research and development (Garratt *et al.*, 2007). Larsen (2010) developed an unmanned remote controlled helicopter for post disaster surveying to check the changes in the structures of buildings. Proposed UAV system provided the cheap and reliable solution to analyse the structures before and after disaster situations.

Unmanned Aircraft Systems (UASs) extend human potential and allow the execution of dangerous and difficult tasks safely and efficiently, while saving time, money and lives. UAVs are preferred over manned aerial vehicles due to their versatility in various terrains and conditions, as they can perform a multitude of roles, including the following: dirty (chemical contamination and spraying), dangerous (military combat situations), covert (surveillance and espionage) and research roles. Chou *et al*. (2010) used UAV to study and capture the real-time images after natural disaster struck in Taiwan. They suggested UAVs as mobile, flexible, weather repellent and an overall appropriate choice for the post-disaster surveying. The real-time data captured via UAV can be used to determine the overall damage assessment and future losses as well. Furthermore, the UAVs are more environment friendly and economical to operate, when compared to their manned counterparts (Nedelcut, 2011).

Onosato *et al*. (2006) presented the idea of using different robotic systems together with UAV to continuously gather disaster related information. Authors used autonomous helicopters collect data and a cable-based robotic system to survey the area for victims using a balloon bird eye system (Meyer *et al*., 2009). Renewable power sources (such as, solar and wind-based energy systems) can be used within the proposed system to enhance the overall endurance time.

Yamamoto *et al*. (2013) developed a low-cost unmanned helicopter system for disaster counter measures. Authors presented the idea of transmitting the video on-line over WLAN rather than using expensive video transceiver set-up. UAS has been used for civilian purposes in different departments (Skrzypietz, 2012). In the field of environment protection, UAS are used for oil field observations, water resources protection (Lomax *et al.*, 2005), illegal fishing, etc. In communication department, UAS are used as a substitute for satellite and broadband communication (Ayyagari *et al*., 2000, Tozer and Grace, 2001). UAS are also used for infrastructure protection, agricultural uses (Zhang and Kovacs, 2012) and homeland security (Bolkcom, 2004).

MATERIALS AND METHODS

This section includes the statement of problem, methodological approach and the research design in general. Developing countries generally lack adequate resources to deploy in the event of a natural disaster and the only available resources belonging to the country's Armed Forces are generally very expensive to deploy on an extensive scale. However, the use of UAS technology can lead to higher effectiveness and lower cost of operations and deployment on a large-scale.

This research addresses the issue of providing a cheap solution for post-disaster surveying using unmanned helicopter. To develop unmanned LR disaster relief and survey helicopter, extensive research is in-progress at the Aerial Robotics Lab, National University of Science and Technology (NUST), Islamabad, Pakistan. Methodological approach adopted to develop the unmanned helicopter is division of overall project into smaller sub-projects. Once all sub-projects were completed, they are planned to be integrated to get the final product. Proposed approach towards the problem is to use the available components in the market and develop a base platform. Once the base platform is developed, it has been planned to enhance the platform by installing supporting systems on it required to achieve desired disaster surveying task. Overall block diagram of the project distribution is shown in Fig. 1. A medium size unmanned disaster relief helicopter being developed at Aerial Robotics Lab, NUST, Pakistan, is shown in Fig. 2.

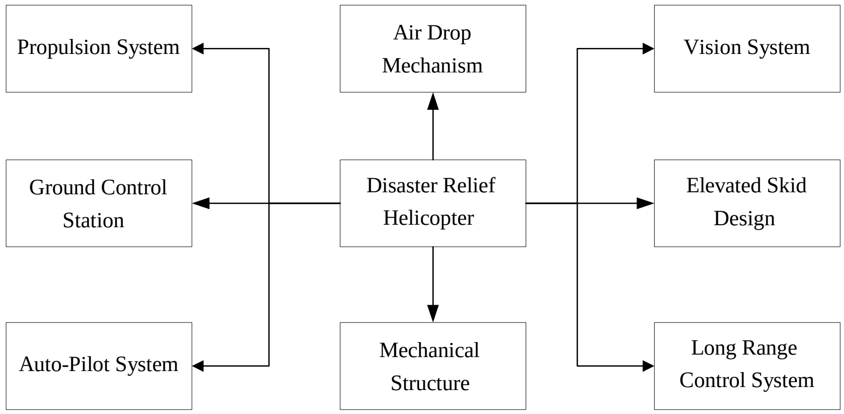


Fig. 1: Overall distribution block diagram of unmanned disaster relief helicopter project.

Fig. 2: Velocity 90-based medium size unmanned disaster relief helicopter under development at Aerial Robotics Lab., NUST, Pakistan.

Main objective of the research presented in this article is to plan, implement and test LR radio control system, to develop a test bench for ground testing and the implementation of the LR radio control system on the helicopter. The idea of developing test mock-up was used to provide the independency from working on actual helicopter and to test the developed radio control system in different configurations. The LR system has been implemented in different steps, which include the following: (a) identification of available LR radio communication modules in the market, (b) feasibility study and performance comparison of identified LR radio systems, (c) selection of radio system and other parts based on suitability and utility, (d) design of the LR system, (e) integration of selected parts to practically implement the system and (f) ground testing of the developed system on test bench before implementing it on the helicopter.

In a radio controller, a Pulse Position Modulated (PPM) signal containing the position for servo motors is generated, which is modulated with a 2.4 GHz signal before transmission. At the receiver (Rx) end, the PPM signal is demodulated and provided to the servo motors to create required displacement for changing the position of different shafts on the helicopter. The complete process outlined above is shown in Fig. 3(a). The existing control system accompanying the helicopter operates at 2.4 GHz frequency and claimed by manufacturer to work in the range of 2 km. But, according to the tests performed by Iqbal *et al*. (2014a), system provided continuous communication within a maximum range of 1.1 km on Line of Sight (LOS). In stand-alone conditions, the helicopter cannot be flown beyond 300 m, due to the orientation issues, but with LR video data telemetry system installed, distant flights can be achieved given that helicopter engine and power sources are capable of distant flights.

A block diagram of the proposed scheme for LR radio control system is shown in Fig. 3(b). LR transmitter (Tx) is connected to the existing radio controller via trainer port and the Rx antenna is also replaced with the diversity LR receiving antenna. Connection of LR radio module via trainer port automatically disabled the existing 2.4 GHz radio module, which provided the flexibility of using both normal range and LR systems without any hardware modifications. For range testing, the angle variations in the servo motor are monitored over a considerable distance. To capture the PPM signals in real-time for Tx and Rx, Data Acquisition (DAQ) card based setup has been used. Due to high frequency of Tx signal, normal oscilloscope was unable to capture it and hence DAQ card with LABVIEW setup was used to capture the PPM signals.

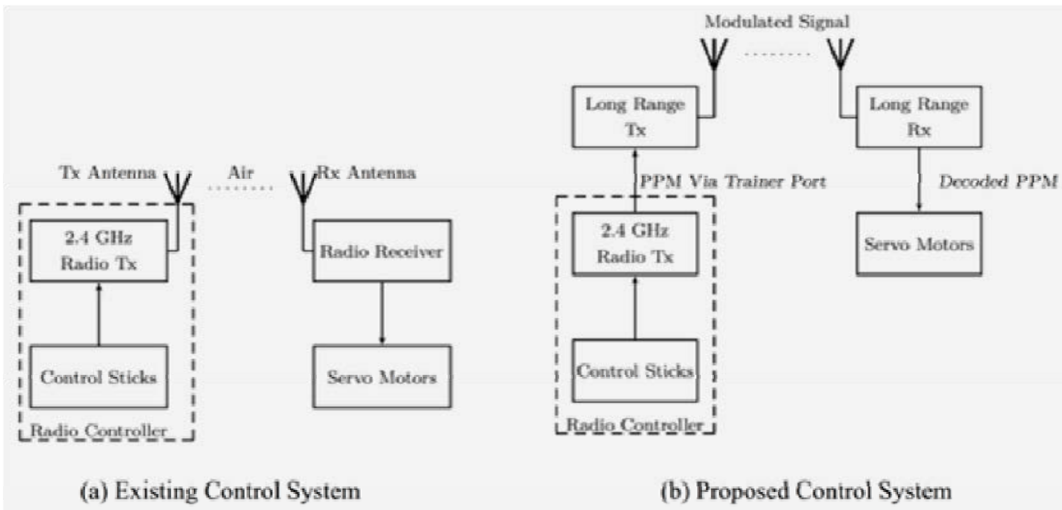


Fig. 3: Block diagrams of existing and proposed radio control systems.

Implementation of proposed long range radio control system design

This section presents the implementation of LR radio control system and includes details about parts identification and hardware implementation of the proposed system.

Parts identification: This section includes the identification and specifications of the parts, required to develop the proposed LR radio control system for unmanned disaster relief helicopter. Velocity 90 hobby helicopter has been used as a base platform. Details regarding the three servo motors used for the movement of helicopter (for changing the roll, pitch and yaw angle) are presented in Table 1. Fourth motor is used for throttle and the other is used for stabilizing the helicopter. Spartan Quark Microelectromechanical Systems (MEMS) gyro is used for the automatic stabilization of the helicopter.

Table 1: Specifications of Servo Motors.

Model	Operating Voltage (V)	Torque (kgcm)	Dimension (mm)	Weight (g)
Hitech 7940	4.8-7.4	13	40 × 20 × 38	68
Allign 610	4.8-6.0	12	40.3 × 20.1 × 36	52.2
Outrage 9188	5.2-8.4	4.45	39.88 × 20 × 38.6	60.95

JRDSX9 controller has been used as base Tx, that was then hooked-up with LR Ultra High Frequency (UHF) Tx to get LR transmission. Thomas Scherer Long Range System (TSLRS) Tx module with three different transmission power choices, 500 mW, 1000 mW and 2000 mW has been used as UHF Tx. Supply power usage is accordingly increased depending upon the power mode. Normally, supply power usage is three time the Tx power. Antenna impedance of used connect the LR system with controller. PPM signal must contain 4-12 servo motors otherwise will be refused by Rx. LR 12-channel diversity Rx system is used with sensitivity of −120 dBm.

Hardware implementation: This section includes a step-wise implementation of proposed methodology for development of LR radio control system for disaster relief helicopter. There are different LR radio systems available for extending the radio been used, due to its quality and reliability in comparison to other available systems (Iqbal *et al.*, 2015b). The basic idea used to extend the range as to route PPM signal from the existing radio controller and provide it to the UHF Tx. LR Rx configuration with servo motors is given in Fig. 4(a). An overall electronic configuration for interfacing UHF Tx with existing system is shown in Fig. 4(b).

The transmission of the radio signal is undertaken using the Frequency Hopped Spread Spectrum (FHSS) technique, in order to reduce the impact of interference and noise on the received signal strength. FHSS transmits radio signals by switching carrier over a specific range of frequencies, using pseudo sequence known to both ends. Spread spectrum is usually preferred over fixed frequency in radio communication due to its high resistance to narrow band interference, difficulty of intercepting signal (improved security constraints, which make it appropriate for military-related and other sensitive applications) and overall improved bandwidth efficiency. In civilian applications, FHSS is used in Radio Controlled (RC) UAVs to facilitate proper working of multiple transmitters in the same area without signal interference between different transmitters by assigning unique id to each Tx and Rx set-up (Peterson *et al*., 1995).

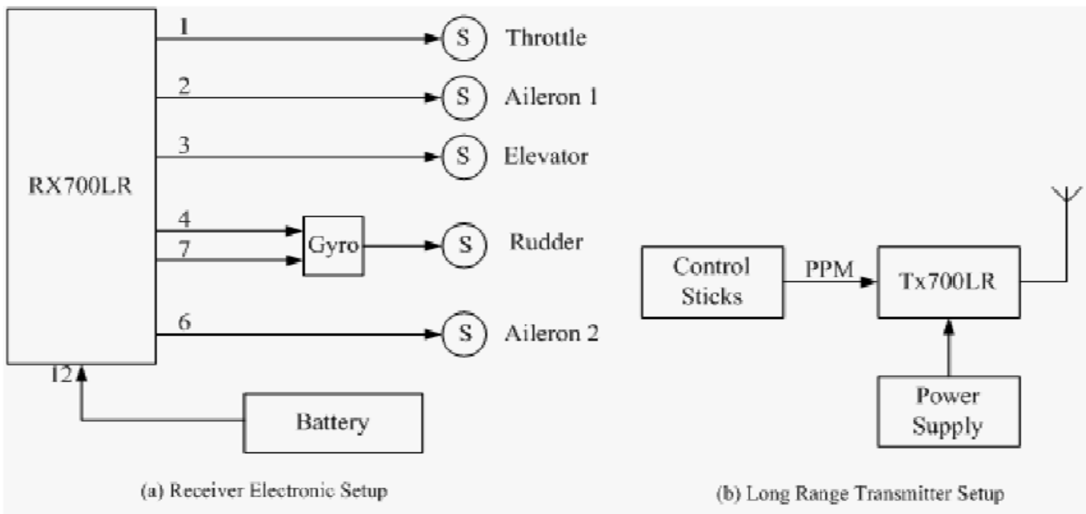


Fig. 4: Implementation setup for long range radio control system: (a) Receiver electronic set-up, (b) Long range transmitter set-up.

Interfacing UHF Tx with the base Tx can be a complicated task. There are many possible methods to acquire the PPM signal out from the base Tx (in this case JRDSX9) depending upon the priority. One solution is to open up the base Tx, track the PPM signal and provide it to the UHF Tx by soldering a wire through that path. This method provides a powerful PPM signal but it may also cause damage to the connected equipment in case of wrong connections or other issues. Another relatively safer method is to use the trainer port of base Tx (if available) to get the PPM signal, but the acquired signal is weaker as compared to the first method. In this research, trainer port method was used by soldering the mono (stereo cable can also be used) plug cable and attaching external power source with the UHF Tx.

However, connecting the UHF Tx to base Tx battery reduces the endurance time and using the stereo cable with the JRDSX9 trainer port causes issues related to proper working of the system. UHF Tx should be mounted on the base Tx for acquiring an appropriate antenna orientation. In this research, the UHF Tx and power sources are temporarily mounted

flight of an unmanned helicopter can be developed for around $2000, which is not very expensive, especially when comparing the costs of deploying and maintaining a full-size manned helicopter.

In order to support the argument that unmanned helicopters provide cheaper solution for surveying and monitoring purposes, Table 2 presents the estimated cost comparison between both platforms. Even from the rough cost comparison, the huge difference between the costs can be observed. In terms of gross cost, unmanned helicopters are more economical, as compared to the manned helicopters ($13000 in comparison with $15000000). Importantly, while estimating the expenses of survey and rescue missions, it is not the gross cost, but the maintenance and crew cost. Manned survey missions are a way too expensive compared to the unmanned survey missions ($15000 per hour in comparison with $1000 per hour). Table 2 also presents the estimated cost comparison for a 2-hour survey mission for both manned and unmanned helicopters (Haddal and Gertler, 2010).

Table 2: Estimated cost comparison between manned and unmanned rescue helicopters.

	Manned helicopter	Unmanned helicopter
Gross cost	≈$15000000	≈$13000
Maintenance + Crew per hour	≈$15000	≈$1000
Cost for 2 hours mission	**≈$15030000**	**≈$15000**

RESULTS AND DISCUSSION

This section includes the testing results and analysis of the proposed system. Important signals from different parts of the system are measured, recorded and analysed, using data acquisition set-up. The two most important quantities measured during testing include the angle measurement (for range calculation) and endurance (for calculating time of flight). For angle measurement test mock-up has been used to record relevant results. For endurance testing, current drawn by the proposed Tx and Rx setup has been measured and recorded. From the average drawn current value and battery Ampere hour value, the approximate time of flight (the amount of time for which the helicopter can fly using the existing power source) is calculated. The Rx is tested twice: firstly without the load and secondly after applying the relevant load to measure the required current values. To test the radio range of the developed system, a mock-up has been developed to analyse the movements of servo motors and monitor the changes in servo motor angles (if any) from different test points.

Initially, for the range testing, four test points were selected, using Google Earth to approximate the LOS from the elevation profile information provided. Test points, used for testing, were point A(33°41′ 35.64″ N, 73°4′ 5.20″ E), point B(33°44′ 15.90″ N, 73°3′ 24.50″ E), point C(33°53′ 8.26″ N, 73°22′ 12.40″ E) and point D(33°53′ 41.29″ N, 73°22′ 43.23″ E) at a distance of 9.6 km, 12.9 km, 44.8 km and 48 km, respectively.

Angles of servo motors for extreme commands at 5 m distance have been measured, using developed mock-up, and were used as reference. Table 3 shows the movement of servo motors in degree at 5m distance. Fig. 5(a-c) shows the plots of angles variations for the extreme throttle, elevator and aileron commands from the described test points. The down peaks in the plots show the loss of communication due to LOS problem.

Table 3: Reference Servo Motors angles Measured at 5 m distance.

Command	Throttle	Aileron 1	Aileron 2	Elevator
Full throttle up	100 CW	0	50 CW	0
Full throttle down	100 CCW	0	50 CCW	0
Full elevator up	0	0	0	40 CW
Full elevator down	0	0	0	40 CCW
Full aileron right	0	40 CW	0	0
Full aileron left	0	40 CCW	0	0

From point A, it has been observed that the communication and signal strength was stable and smooth, even with Tx at low power mode. No changes in the angles of servo motors were observed, except for some random servo errors from reference.

From point B, the communication was successfully established at low power mode, but due to very narrow LOS, visibility issues and low altitude problems, communication was only established at certain locations of Tx. Once the communication was established, there were hardly any changes to the servo motor angles except random errors.

From point C, there was no communication established between Tx and Rx due to very narrow LOS and other visibility issues. From point D, communication was established, but only for certain antenna configurations on some points on the location, due to narrow LOS and visibility problems. Once the communication was established, it was stable and there were no changes in servo motors angles or powers at extreme commands except some random error values were generated.

From point D, the communication was established at high power mode and there was no communication on low or medium power modes.

All the tests were conducted on-ground and within the available test points, maximum range tested, using standard Yagi antenna, and diversity Rx was approximately 48 km. Sharp curves in the graphs of range testing indicate the digital response of RX, which means that there were only two situations, either there was stable communication or there was no communication at all. Although, from this explanation, it seems that these tests were unnecessary to perform, however, the main purpose here was to monitor the variations in angles with respect to distance so that flyer can have an idea as to what extent manual controls are needed to be adjusted.

The PPM signal in the existing setup contained information on 10 channels and it was extracted from JRDSX9 using DAQ card. The repeat time of the measured signal was 20 ms and pulse width was 40μs. PPM signal decoded by the diversity Rx to servo motor was also recorded, using DAQ card. It provided

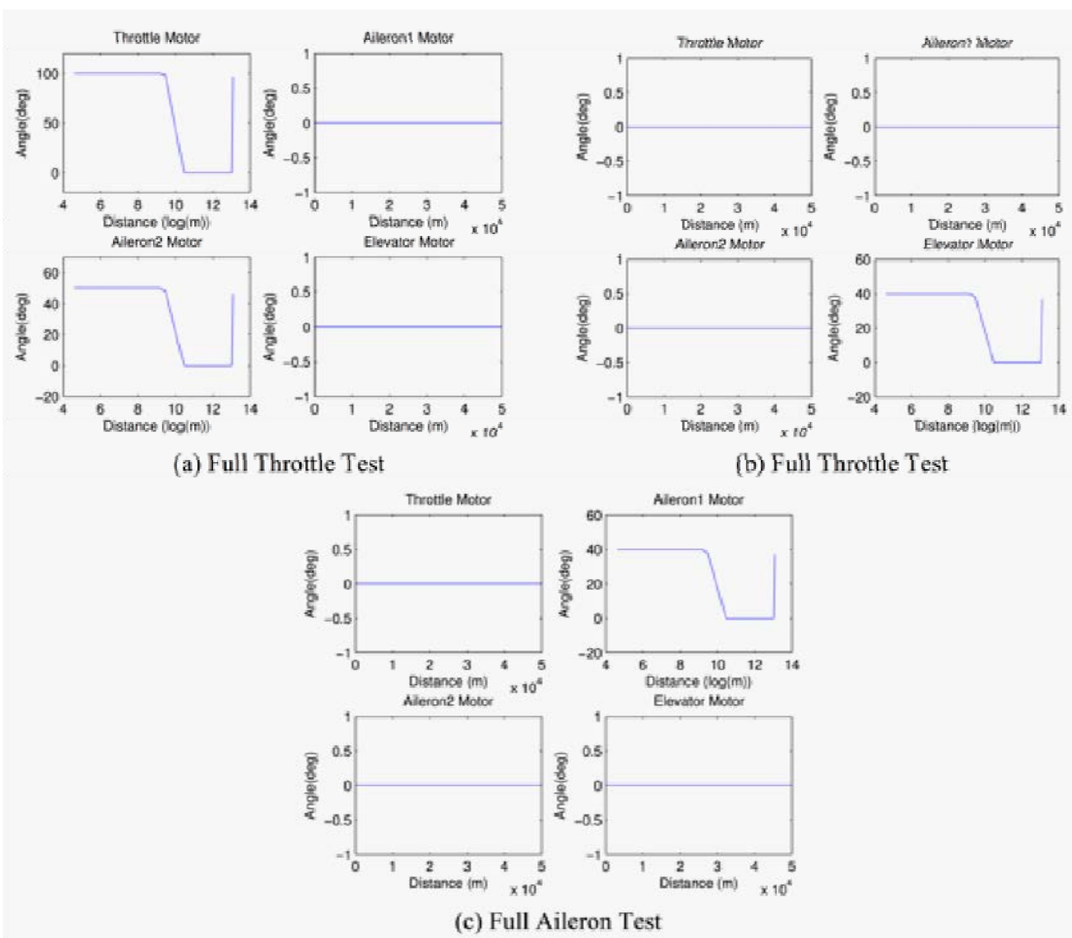
+3.3 V pulse servo with repeat time of 20 ms and pulse width of 3 ms.

Endurance testing of proposed system; real-time current drawn by the Tx and Rx setup was measured, recorded and plotted. The drawn current was recorded with setup in continuous working condition and then an average current value was related with the battery Ampere hour rating to predict the maximum working time of the helicopter with the available power source.

Fig. 6(a) shows the current drawn by the radio controller when LR module is connected via trainer port that drew an average of 116.9 mA current. For the 1500 mAh Tx battery, flight time of 12.8 hours was estimated.

Fig. 6(b) shows the current drawn by LR Tx at different operating modes. At low power mode, it drew 0.3 A current, at medium power mode, it drew 0.45 A current and at high power mode, it drew 1.18 A current. For the 1500 mAh battery, flight times of 13.6 hours, 9.1 hours and 3.18 hours were estimated, respectively.

The current drawn by Rx setup with servo motors having no load was tested on the test bench developed for the radio range testing. There were significant variations in Rx current while system was operating due to fast switching of servo motors during flight. A plot of drawn current on no load condition is shown in Fig. 6(c). On an average, Rx set-up drew 0.21 A current and was estimated to work for approximately 19.5 hours, but the variations in drawn current were significantly changed when servo motors were connected with helicopter in ground position with actual swash plate and rotor blade loads. Fig. 6(d) shows the current drawn by the Rx setup when actual helicopter load was applied. On an average, it drew 1.73A current. To predict the maximum operating time of system in load condition, first standard deviation value was used due to large variations. It was estimated to work for 1.4 hours in loaded condition while the helicopter was on ground. Fig. 6(e) shows the current drawn by the system when motors were connected on helicopter with actual load and rotor was in running condition on ground. It was observed that current drawn reduced in running condition, as the motors were no longer in hold condition. On an average, it drew 1.38*A* current and was estimated to work for 2.97 hours. Hence, talking about overall system JR Controller battery worked for approximately 2 hours. With the current configurations, it has been estimated that the system will work for approximately 1.5 hours. By adding extra power source at Rx end endurance time can easily be extended up-to 2 hours.



(a) Full Throttle Test (b) Full Throttle Test

(c) Full Aileron Test

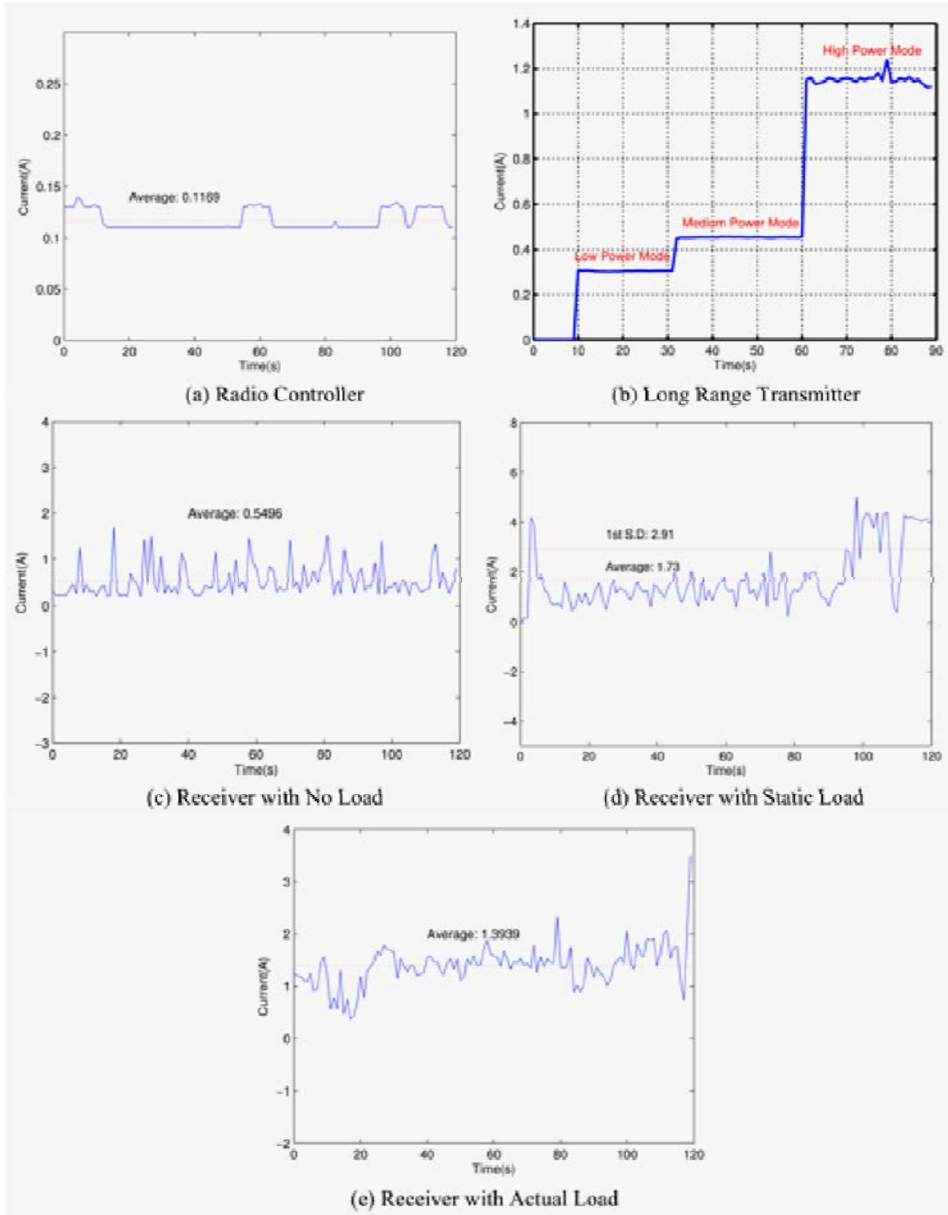


Fig. 6: Endurance testing current plots for long range control system.

It is important to mention that, endurance analyses performed in this article are only for the LR radio control system proposed for the helicopter. Flight time has been predicted based on the current drawn by the helicopter with LR radio control system in helicopter rotor running condition. These are basic analyses and for more realistic endurance analysis, statistical methods should be used to predict the flight times from the actual data recorded during the flight, which is one of the future prospective of this project. A more detailed endurance analysis of the unmanned helicopter with other possible systems and performance of helicopter are discussed by Iqbal *et al*. (2014b).

CONCLUSION

LR radio control system for unmanned disaster this study. The developed system's performance was monitored using two measures, namely range testing and endurance testing. From Fig. 5 and the subsequent discussion, a maximum range of 48 km has been tested at LOS for the developed system. Approximate endurance analysis is highlighted in Fig. 6 by predicting the flight time of the system using the values for current drawn by batteries in real-time. Based on the testing results and its analysis, it can be concluded that the existing power supply will allow the unmanned helicopter to remain airborne for 2.5 hours of time.

In Pakistan, although there are major natural disasters every year, yet low cost survey and relief systems are not available. Unfortunately relevant literature is also limited. The proposed and developed LR radio control system for disaster relief helicopter the helicopter is fully developed, it is expected to be the first unmanned helicopter for disaster relief and monitoring operations in Pakistan. Hence, the development of unmanned helicopter for disaster relief is expected to be a significant national contribution. Besides proposed endurance, testing and range testing methodologies are the methods which have not been applied before for RC vehicle applications. These techniques can prove helpful in ground testing and flight time predictions of UAVs.

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